

Physics Parameterization for Seasonal Prediction

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LONG-TERM GOALS

This 6.1 project is part of a long-term effort to identify and solve the major challenges of parameterizing the impacts of physical processes on atmospheric predictions extending out to seasonal time scales. Achievement of this goal will represent a significant step towards the development of an operational global earth system model targeted by the national Earth System Prediction Capability-Research, development, and Operations (ESPC-RDO) effort, in which the United States Navy is a participant.

OBJECTIVES

This project targets development of a “unified” treatment of atmospheric mixing processes, including interactions with clouds, within the Navy Global Environmental Model (NAVGEM) suitable for extended range prediction that includes not only boundary layer mixing, but mixing by shallow to mid-level convective clouds, as well as deep convection. The project will pursue a more consistent and realistic treatment of the relative magnitudes of these various mixing processes, focusing on the hydrologic cycle, but also addressing related momentum drag balance issues.

APPROACH

We are focusing on ensuring a more comprehensive representation of key processes in the hydrologic cycle in NAVGEM. Some critical steps have been taken during the past couple of years with the implementation of a two-species prognostic cloud scheme and separate treatments of deep and shallow convection. We continue to work towards improved fidelity of our physics codes to current understanding of atmospheric processes, and are seeking to adapt and test new physics treatments as well, particularly those developed under this DRI. A key question remains concerning the key physics requirements for simulation of important modes of predictability on extended timescales, particularly the Madden Julian Oscillation (MJO). We are continuing our participation in the project “Vertical Structure and Diabatic Processes of the MJO”, a joint effort between the Year of Tropical Convection (YOTC) Program and the Global Energy and Water Cycle Experiment (GEWEX) Cloud System Study (GCSS). This large collaborative effort is investigating the sensitivity of the representation of the MJO to various model formulations, providing us an excellent opportunity to leverage our development

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efforts under this DRI project. Evaluation of progress achieved will include a range of global data sets, and will be aided through analysis of errors on shorter timescales using the state-of-the art data assimilation component of NAVGEM.

The key performers on this project are Drs. James Ridout (PI) , Maria Flatau and Shouping Wang, all employed by NRL in the Marine Meteorology Division, and Dr. Jan-Huey Chen, a UCAR visiting scientist at NRL.

WORK COMPLETED

1) Cloud Fraction Parameterization. This year our parameterization work focused on extending the development of a more unified treatment of clouds in NAVGEM, building upon the development in FY12 of the NAVGEM 2-species prognostic cloud scheme under this project. The prediction of cloud water and ice in the model provides important new information for parameterization of cloud fraction, a key factor for cloud radiative impacts. Building on current techniques, we developed for stable clouds in NAVGEM an implementation of the Xu-Randall (1996) cloud fraction scheme. The Xu-Randall scheme establishes a correspondence between cloud fraction cf and cloud condensate according to the relation:

$$cf = RH^{k_1} \left[1 - \exp \left(- \frac{k_2 q_c}{[(1-RH)q_s]^{k_3}} \right) \right] \quad (1)$$

where q_c is the condensate mixing ratio, q_s is the saturation specific humidity, RH is relative humidity, and k_1 , k_2 and k_3 are parameters. The link between cloud condensate and cloud fraction feeds back to condensation through the radiative tendencies. Note that cloud fraction vanishes under this treatment where there is no condensate. Parameter values in the published scheme are based on a cloud ensemble model simulation for Phase III of GATE. Although independent comparisons with aircraft data (Wood and Field 2000) from several observational programs show reasonable fits, there is a fair amount of spread, and some latitude was taken in adjusting the parameters for use in NAVGEM. The implementation for NAVGEM includes a treatment to estimate the portion of the condensate mixing ratio corresponding to stable clouds, which is the component used in (1). This estimate is based on the relative amounts of parameterized stable and convective cloud cover and corresponding representative mixing ratios used in the Harshvardhan radiation scheme in NOGAPS (e.g., Ridout et al. 1994). In conjunction with the Xu-Randall cloud fraction scheme, the stable/convective characterization of the condensate was also utilized in the 2-species cloud scheme to account for differences in the cloud physics expected for stable versus convective clouds.

The implementation of the Xu-Randall scheme for stable clouds in NAVGEM was combined with further enhancement of the convective cloud fraction scheme developed in FY12. This scheme has not been published yet, but for simplicity will be referred to here as the “Ridout” scheme. The new scheme replaces the vertical profile assumed in the Slingo (1987) treatment with an assumed relative humidity and density dependent scaling. The resultant parameterization for convective cloud fraction cf has the form:

$$cf = cf_{cb} \times f(rh, \rho) / f(rh_{cb}, \rho_{cb}) , \quad (2)$$

where rh is relative humidity, ρ is density, and the subscript cb designates cloud base values. In its current application, the magnitude of the amount by which the cloud base cloud fraction is scaled is confined to between 0.5 and 4.0. As described in the FY12 report, at cloud base, cf is assumed to vary with convective rainfall rate $rain$ (cm h^{-1}) as in Slingo (1987), but with a scaling by cloud base mass flux mf_{cb} :

$$cf_{cb} = \left(\frac{0.93 + 0.124 \ln(rain + 0.001)}{0.93 + 0.124 \ln(0.001)} \right) \times mf_{cb} \times 2. \quad (3)$$

In contrast with the Slingo scheme used for years in NOGAPS, the added mass flux scaling allows the convective cloud fraction to smoothly approach zero in the limit as parameterized nonprecipitating convective activity vanishes. Cloud cover variations above cloud base are parameterized by the function $f(rh, \rho)$ given by

$$f(rh, \rho) = \frac{\exp(-2(1-rh)) \times 6 \times \rho_{cb}}{(1+10(1-rh)) \times \rho}, \quad (4)$$

which was formulated to roughly represent various impacts of moisture on cloud cover, as well as parcel expansion upon lifting through cloud base to various detrainment levels. Convection plays a critical role in moistening the free troposphere, and one expects an increase in convective cloud cover associated with greater time-integrated amounts of detrained cloud water and vapor. In this view, relative humidity plays a dual role, reflecting to some degree the amount of detrained condensate, as well as the degree to which evaporation can be expected to limit consequent increases in cloud fraction. Although the NAVGEM 2-species cloud code to some degree represents convective condensate in the grid-scale cloud water variables, the viability of representing convective cloud cover directly from these variables has not yet been fully explored.

2) Testing. Our parameterization testing has continued to focus on key large-scale modes of variability, in particular the MJO and equatorial Kelvin waves. In FY13 we carried out another 20-year integration of NAVGEM to experiment with a revised treatment of entrainment in the Simplified Arakawa Schubert convection scheme (e.g., Han and Pan 2011). The revision, a treatment by Lee et al. (2003) did not offer any significant improvement over our first integration, which is the one that was submitted for the YOTC/GEWEX global model intercomparison. A number of other shorter multi-year runs were carried out this year in our internal parameterization testing. We are currently focusing on a continuation of our MJO hindcast tests using the second of the two test cases from the intercomparison experiment. We have initiated a new series of hindcasts for this case, which we plan to analyze in collaboration with Professor Zhuo Wang from the the U. of Illinois.

An important component of our effort this year has been testing of parameterizations from other DRI projects. As part of this work, we began testing in NAVGEM an EDMF scheme comprised of a mass flux parameterization from Drs. Kay Sušelj and Joao Teixeira (Sušelj et al. 2012) combined with the Louis et al. (1982) boundary layer parameterization. The scheme has been recently transitioned to operational use, but our interest here is in its implications for extended range prediction. From a physical perspective, the scheme fills an important gap in NAVGEM physics; it parameterizes mixing by updrafts forced by boundary layer turbulence in convective boundary layers. More recent test versions extend its function to mixing in dry rather than only cloud-topped boundary layers. This year

we tested the initial scheme delivered to us in multi-year integrations of NAVGEM. In addition we have provided feedback on concerns about particular features of the scheme, including a significant lack of conservation we discovered towards the end of the FY, for which we have recommended a fix. Conservation is of course a key concern as we look towards extended range prediction.

We have also begun testing the air-sea flux scheme from Dr. Ed Andreas (Andreas et al. 2012). After some preliminary tests and feedback from Dr. Andreas, we determined that the initial implementation in NAVGEM will require some revision. The scheme is designed to predict surface fluxes, but in NAVGEM mixing coefficients are extracted and surface fluxes are computed through an implicit solver along with the subgrid vertical mixing. The full scheme with sea-spray effects included was delivered at the end of the year, so has yet to be implemented and tested.

3) COAMPS Evaluation. COAMPS simulations were performed to evaluate the model performance and understand cloud mesoscale structure in the California central coast area during the 2012-2013 Unified Parameterization for Extended Forecast (UPPEF) field campaign. This work was done in collaboration with Professor Qing Wang at the Naval Postgraduate School.

RESULTS

a) Cloud Fraction Parameterization. The Xu-Randall stable cloud / Ridout convective cloud fraction combination was tested in both NWP and extended range integrations. The combination was found to perform well as a component of the NAVGEM forecast model physics in an extensive testing period, but a dearth of stratocumulus cover when paired with the EDMF scheme proved unacceptable for operational use. An example of the total cloud fraction produced by an early version of the new cloud fraction treatment (and run without the EDMF scheme) taken from a series of 24-h forecasts for August 19 – 30, 2012 is shown in Fig. 1 compared with the corresponding MODIS product.

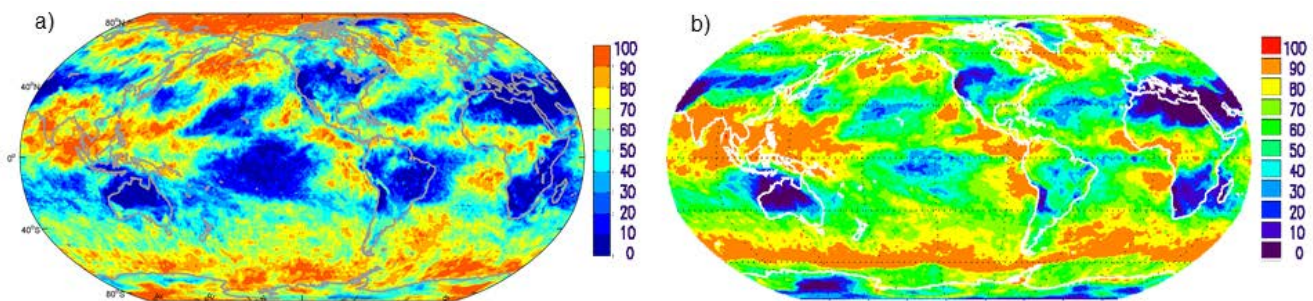


Figure 1. Total cloud fraction for August 19 – 30, 2012 from: a) NAVGEM 24-h forecasts using the Xu-Randall / Ridout cloud fraction scheme, and b) MODIS.

There is no corresponding MODIS product for low-level cloud fraction to validate the low-level clouds with, though the low-level cloud cover fields (not shown) suggest ample amounts off the west coast of continents. Changes to the convective cloud cover scheme have been made since the set of forecasts represented here were run which will hopefully improve the coverage in some of the oceanic regions. Further tests in combination with the EDMF scheme are planned as development of the EDMF scheme progresses.

The Xu-Randall stable cloud/ Ridout convective cloud fraction treatment was also tested as part of a series of three-year (2004 – 2006) AMIP type integrations of NAVGEM with SSTs and sea ice cover specified using the NCEP OI SST V2 weekly data. The new cloud fraction treatment showed a positive impact on tropical variability, as evidenced in Wheeler and Kiladis (1999) type wavenumber-frequency diagrams of rainfall, comparing results using simulated and observed (TRMM) rainfall. Results are shown in Fig. 1 for the NAVGEM 20-year run submitted for the YOTC/GEWEX model intercomparison experiment, along with results from the current operational NAVGEM (version 1.1) and NAVGEM using the Xu-Randall / Ridout parameterization:

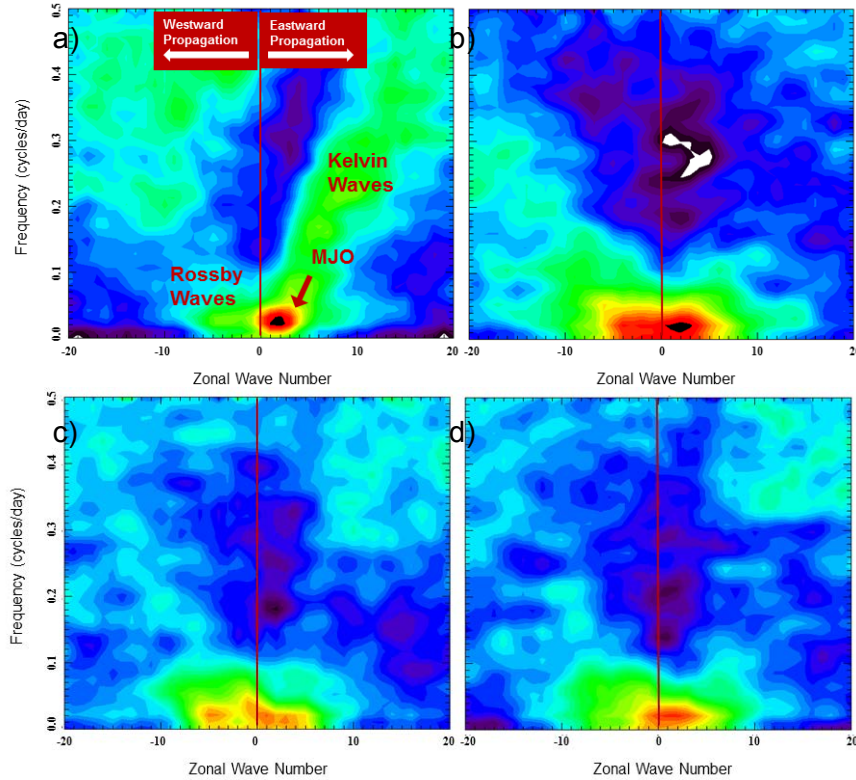


Figure 2. Power spectra of total rainfall in zonal wavenumber / frequency space following the method of Wheeler and Kiladis (1999) for the years 2004 – 2006. Results are shown for: a) TRMM rainfall, b) NAVGEM 20-year run submitted for the YOTC/GEWEX project “Vertical Structure and Diabatic Processes of the MJO”, c) NAVGEM 1.1, and d) NAVGEM using the Xu-Randall / Ridout cloud fraction scheme.

The Xu-Randall/Ridout cloud fraction scheme has less spurious low-frequency westward propagation than the other configurations tested, and has thus far provided the best agreement overall with the TRMM rainfall power spectrum. The low frequency Rossby waves are perhaps still somewhat too strong, and the Kelvin waves continue to present a challenge.

b) EDMF Scheme Tests. The EDMF scheme delivered to NRL Monterey was also tested in the series of three-year AMIP type integrations for 2004 – 2006 described in (a). The scheme was found to produce overly strong westward propagation, as seen in the Wheeler-Kiladis diagrams for total rainfall in Fig. 3. As with the other physics configurations examined, the Kelvin wave signature is very weak.

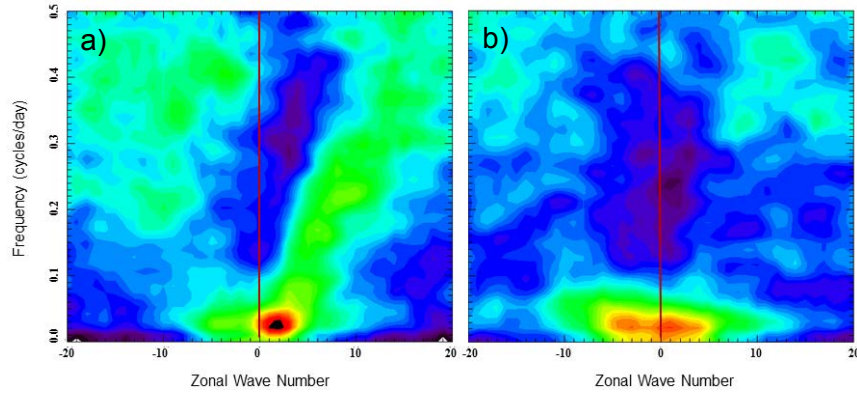


Figure 3. Power spectra of total rainfall in zonal wavenumber / frequency space following the method of Wheeler and Kiladis (1999) for the years 2004 – 2006. Results are shown for: a) TRMM rainfall, b) NAVGEM using the EDMF scheme.

Further development and analysis of the scheme is ongoing. Towards the end of the FY, we discovered that the conservation properties of the scheme could be improved significantly with some minor changes. The implications of the modifications are still being examined, but appear to provide significant improvements to low level temperatures and winds in the Tropics.

c) COAMPS Evaluation. The COAMPS simulations of the California central coast region during the 2012-2013 UPPEF field campaign are consistent with the observations in showing significant mesoscale variability of boundary layer height and cloud distribution; the boundary layer height increases significantly from the nearshore to offshore area. Comparisons with aircraft observations demonstrate that COAMPS simulations produced better boundary layer (BL) structure offshore than close to the coastal area (Fig. 4). For example, the simulated BL height is only about 200 – 300m near the coast compared with 500m in the observations. This result implies that local orographic flow and diurnal variation over land are critical in realistically simulating the coastal marine boundary layer clouds. Furthermore, the coarser grid (15km) produced considerably lower MBL heights than the finer grid (5km) near the coast.

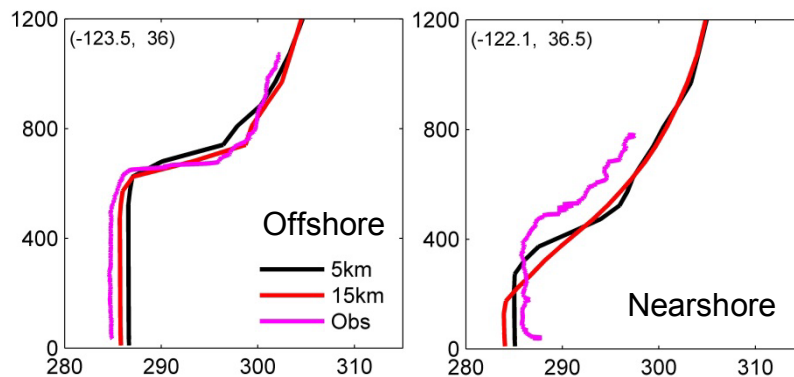


Figure 4. Comparison between the observation and COAMPS simulations from 2 nested grids at offshore and nearshore locations on 17 Sept. 2012.

It is likely that simulated downward motion associated with the topography is unrealistically strong, suppressing the growth of the MBL.

IMPACT/APPLICATIONS

The parameterization development under this project is expected to contribute to future strategic planning capabilities of the United States Navy. In addition to helping enable skillful extended range prediction, benefits to current short- to medium range forecasting capabilities are also expected.

TRANSITIONS

The two-species prognostic cloud scheme and the modified cloud fraction treatment described in FY12 were successfully transitioned to operations at FNMOC.

RELATED PROJECTS

NOGAPS/NAVGEM Platform Support (PI Dr. T. Whitcomb). This related project is expected to benefit the 6.1 project discussed here by facilitating coordination of efforts with collaborators on other projects funded through this DRI.

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